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Establishment and first results of a jack pine breeding program for Manitoba and Saskatchewan

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ESTABLISHMENT AND FIRST RESULTS OF A JACK PINE BREEDING PROGRAM FOR MANITOBA AND SASKATCHEWAN

J.I. KLEIN

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ABSTRACT

Establishment procedures and the first results are presented for a jack pine (*Pinus banksiana* Lamb.) breeding program for Manitoba and Saskatchewan. The program was begun in 1967 to produce genetically improved seed, seedlings, scions, grafts, or rooted cuttings for the establishment of seed orchards. This report discusses the strategy of the first selection cycle, characteristics of the three breeding districts, assembly of breeding materials, establishment of family tests, operation of an experimental seedling seed orchard, and future program development. Selected families in each breeding district had 5-year progeny mean heights averaging 7-9% above their respective test means.

RÉSUMÉ

Ce rapport décrit les techniques d'implantation et les premiers résultats d'un programme de reproduction du pin gris (*Pinus banksiana* Lamb.) mis en train en 1967 au Manitoba et en Saskatchewan en vue de produire des graines, semis, greffons, greffes ou boutures racinées, génétiquement améliorés, pour la création de vergers à graines. Le rapport discute de la stratégie du premier cycle de sélection, des caractéristiques des trois districts de reproduction, du rassemblement des matériels de reproduction, de l'établissement de tests de descendance, de l'exploitation d'un verger à graines expérimental composé de semis ameliorés et de l'élaboration de programmes futurs. A cinq ans, la descendance des familles choisies de chaque district avait une hauteur moyenne supérieure de 7 à 9% à celle des témoins.

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INTRODUCTION

A program for genetic improvement of jack pine (*Pinus banksiana* Lamb.) in Manitoba and Saskatchewan was initiated in 1967 by the Canadian Forestry Service (CFS) at its Forest Research Laboratory in Winnipeg, Manitoba, and was moved in 1971 to the Northern Forest Research Centre in Edmonton, Alberta. The program's objective has been to produce genetically improved seed, seedlings, scions, grafts, or rooted cuttings for seed orchards in the program area. Mass production of improved trees for operational forest planting will be done by cooperating agencies through management of seed or plant-propagule orchards (Libby 1973) established with this program's output. This report describes progress to 1982 toward selection of superior genotypes originating in wild forest stands and production of genetically improved materials from these genotypes. This first selection cycle will culminate in the production of second-generation progenies from matings among the best first-cycle genotypes. The breeding program will then progress to further improvement by selection from among domestically bred genotypes. A brief discussion of program development from its present status to the second selection cycle is included in this report.

Jack pine is one of the major reforestation species in Manitoba and Saskatchewan along with white spruce (*Picea glauca* (Moench) Voss) and, in Manitoba, red pine (*Pinus resinosa* L.). Forest planting in Manitoba totaled 2 million trees on 1000 ha in 1978 (Manitoba Department of Mines, Natural Resources, and the Environment 1979); jack pine accounted for about one-third to one-half of this total. In Saskatchewan, 9 million trees were planted in 1978 (Saskatchewan Department of Tourism and Renewable Resources 1979), of which about 3 million were jack pine planted on 1700 ha (Klein 1979). Greater demands for wood products in the coming decades may result in increases in the annual harvests from the current levels of about 20 000 ha in each province and in the proportion of the harvested area that is planted (Morgenstern 1979; Reed and Associates 1978). Reed and Associates (1978) estimated that the mean annual increment of jack pine stands in the prairie provinces could be increased from 1.8 m^3/ha for unspaced, assisted natural regeneration to 2.7 m^3/ha for plantations using genetically improved planting stock. The proportionate use of jack pine in future planting programs will reflect to some extent accumulating knowledge about productivity of forest plantations of various species, including results of genetic improvement programs. Manitoba and Saskatchewan have recently initiated genetic improvement programs for white spruce (Segaran 1980; Thompson 1980).

STRATEGY OF THE FIRST SELECTION CYCLE

Superior genotypes will be identified by testing open-pollinated progenies of trees selected in stands of natural origin. Progenies will be rated for productivity based on survival, growth rate, and other traits in the test plantations. Other traits will be scored when the data will improve the assessment of productivity. Such traits could include stem straightness, fiber quality, and injury from identified causes.

The program is intended to produce genetically improved materials for most future jack pine planting in Manitoba and Saskatchewan. Three areas were identified as being likely to include jack pine planting at a level sufficient to justify investment in genetic improvement. A separate set of progenies is being tested in each of these areas, which are termed breeding districts. All but a few progenies originated within their test dis-

trict. Output materials (seed, seedlings, scions, grafts, or rooted cuttings) are presumed to be superior throughout the district in which their source genotypes were tested.

Output materials will be produced primarily in a clone bank. The clone bank is a plantation containing grafts of either the selected wild trees that were the seed parents of the tested progenies or of progeny trees for families lacking grafts of the seed parent. Following measurement of the test plantations in one breeding district, clone bank grafts of the seed parents or sibs of the best progenies will be selected as genetically superior. Scions for grafting or control-pollinated seeds will be obtained from the selected grafts. These scions or seeds, or the plants propagated from them, will be provided to cooperators for establishment of seed orchards.

Control-pollinated progenies of selected grafts or test-plantation trees will be used for a second cycle of genetic improvement as well as for establishment of seed orchards. The average genetic quality of these second-cycle progenies will be equal to the genetic quality of their parents, which were the best genotypes from the first cycle of improvement. Because of genetic variation within full-sib progenies, the best individual trees in the second-cycle progenies will be genetically superior to the best first-cycle genotypes. Genetic improvement realized by establishing seed orchards with output materials from the best trees in second-cycle progenies will be added to the improvement of the superior first-cycle parents.

The rationale for the family testing, breeding districts, and clone bank in this program are first briefly described to provide a frame of reference for the account of program implementation that makes up most of this report. A flow chart (Fig. 1) illustrates the strategy for part of the first selection cycle in one breeding district.

Open-pollinated Family Tests

The base population for the first selection cycle (the first-cycle population) consists of the grafts in the clone bank and the open-pollinated progenies in the family-test plantations. One family consists of one selected wild tree's progeny growing in test plantations plus the clone bank grafts of that wild tree (the seed parent) or of individuals of its progeny. Each family test includes several replicated plantations, each with the same set of more than 200 progenies.

First-cycle selection will identify the grafts and test-plantation trees to be used for production of materials for seed orchard establishment and as parents of second-cycle progenies. Selection will be based on the genetic quality ratings derived from measurement of the test plantations. All clone bank grafts for one family will be rated by the mean test-plantation performance of the family's progeny trees (Namkoong 1979, p. 72; Wright 1976, p. 197). The progeny trees will be rated on their own performance and their family means (Morgenstern 1975; Namkoong 1979, p. 83-84).

Grafts of the seed parents of superior progenies are genetically superior to average trees of their progenies. If the pollen parent sample for every progeny were representative of the entire wild source population, the parent grafts of superior progenies would have twice the superiority indicated by their progeny means (Falconer 1960, p. 120; Namkoong 1979, p. 72). For this program it is more realistic to assume that each progeny's pollen parent sample is representative of the progeny's source stand and that superior progenies are likely to have above-average pollen parents (Wright 1976, p. 173). A superior progeny's seed parent graft has less than twice the superiority of the progeny mean by the same amount that its pollen parent sample is genetically above the source population average (Fig. 2). The lack of accurate information

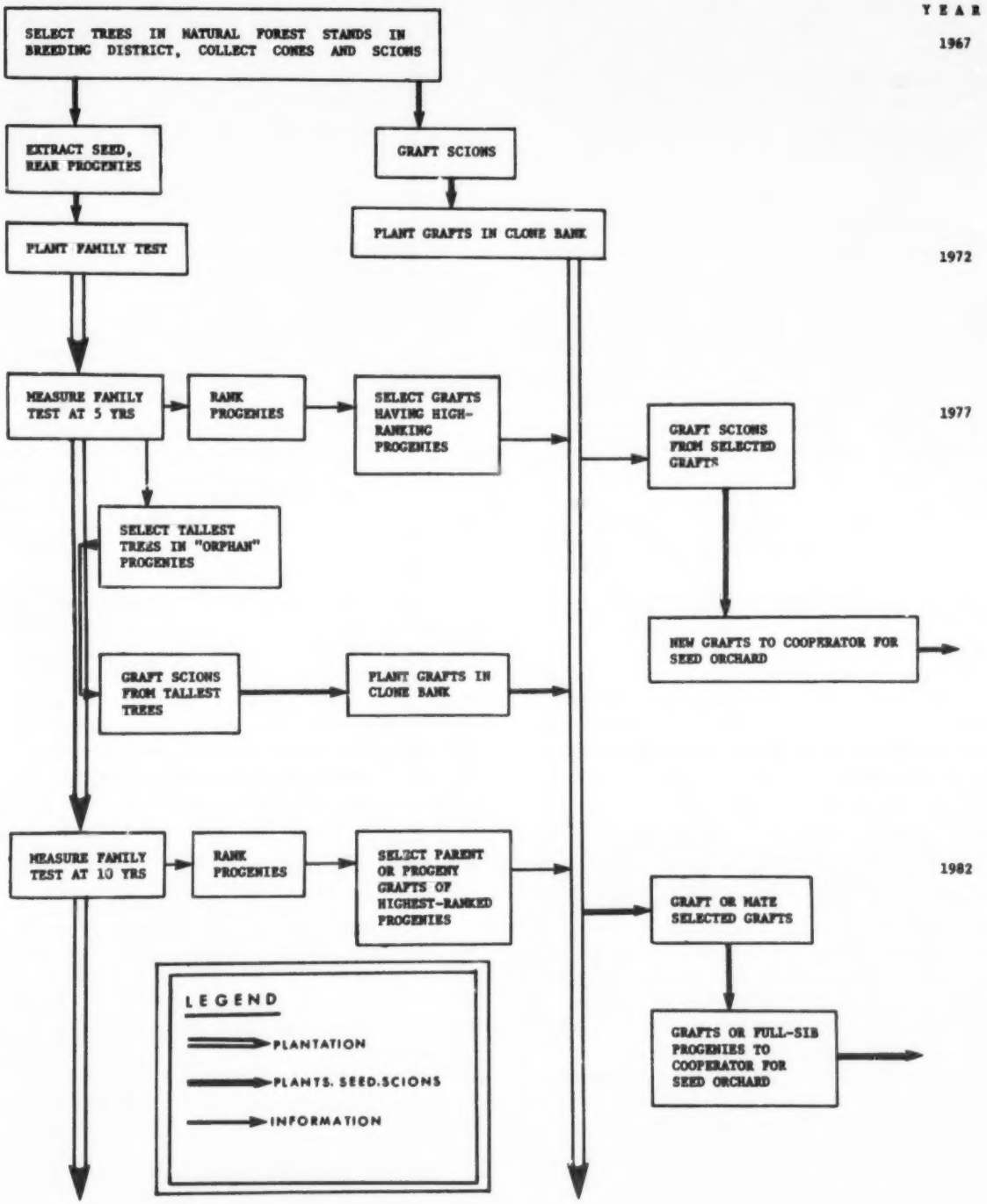
YEAR
SELECT TREES IN NATURAL FOREST STANDS IN BREEDING DISTRICT, COLLECT CONES AND SCIONS
1967
EXTRACT SEED, REAR PROGENIES
GRAFT SCIONS
PLANT FAMILY TEST
PLANT GRAFTS IN CLONE BANK
1972
MEASURE FAMILY TEST AT 5 YRS
RANK PROGENIES
SELECT GRAFTS HAVING HIGH-RANKING PROGENIES
1977
GRAFT SCIONS FROM SELECTED GRAFTS
SELECT TALLEST TREES IN "ORPHAN" PROGENIES
NEW GRAFTS TO COOPERATOR FOR SEED ORCHARD
GRAFT SCIONS FROM TALLEST TREES
PLANT GRAFTS IN CLONE BANK
MEASURE FAMILY TEST AT 10 YRS
RANK PROGENIES
SELECT PARENT OR PROGENY GRAFTS OF HIGHEST-RANKED PROGENIES
1982
GRAFT OR MATE SELECTED GRAFTS
GRAFTS OR FULL-SIB PROGENIES TO COOPERATOR FOR SEED ORCHARD
LEGEND
PLANTATION
PLANTS. SEED.SCIONS
INFORMATION

Figure 1. Flow chart of the first selection cycle, eastern breeding district.

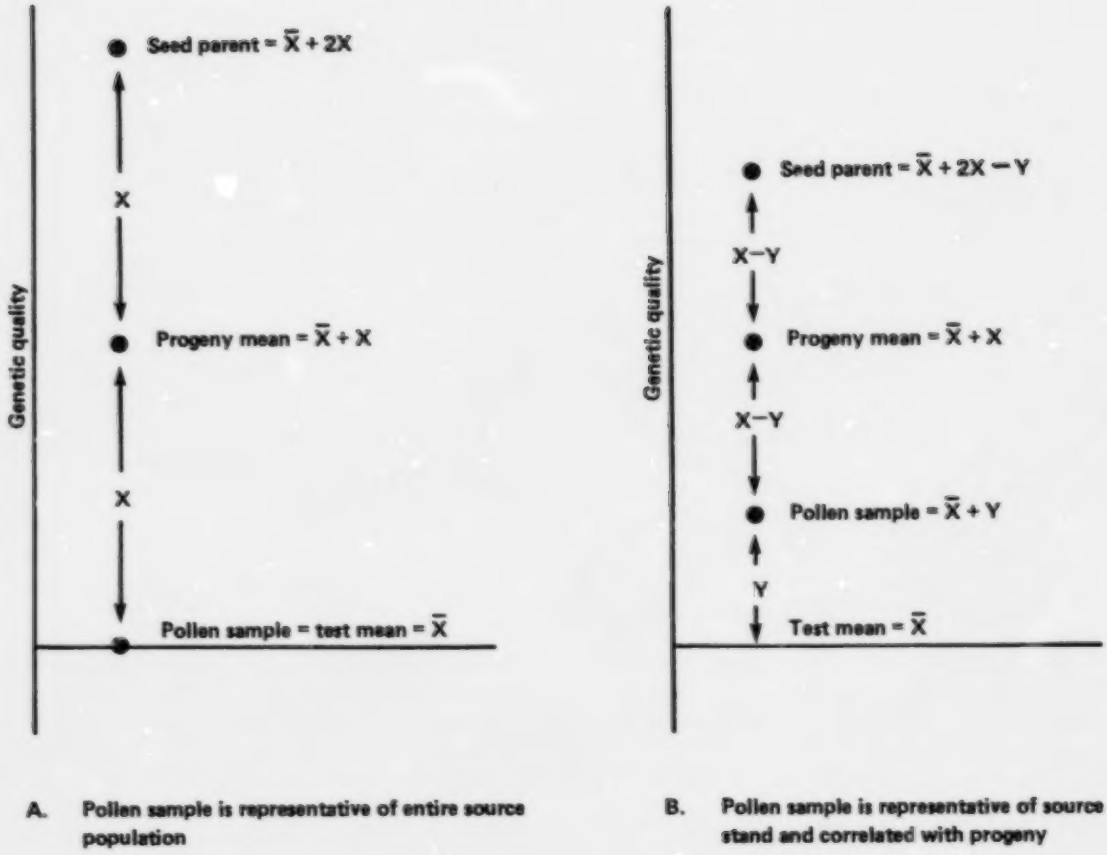
Seed parent = $\bar{X}$ + 2X
X
Progeny mean = $\bar{X}$ + X
X
Pollen sample = test mean = $\bar{X}$
Genetic quality
A. Pollen sample is representative of entire source population
Seed parent = $\bar{X}$ + 2X − Y
X−Y
Progeny mean = $\bar{X}$ + X
X−Y
Pollen sample = $\bar{X}$ + Y
Y
Test mean = $\bar{X}$
Genetic quality
B. Pollen sample is representative of source stand and correlated with progeny

Figure 2. Relationship of seed parent superiority to the progeny mean and to the genetic quality of a progeny's pollen sample.

on pollen parent genetic quality makes it difficult to quantify the superiority of selected seed parent grafts. Nonetheless, the genetically superior seed parent grafts can be correctly identified from the performance of their open-pollinated progenies.

For each family lacking a seed parent clone, scions from five of the family's tallest test-plantation trees (at 5 years from planting) are grafted for inclusion in the clone bank. All of the progeny grafts for one family will be selected as a single unit if that progeny's mean test performance is superior. Progeny grafts are expected to have a slight genetic growth rate advantage over average trees of their respective families because of their within-family selection.

Family-test results will be used to identify test-plantation trees that are genetically superior to some of the higher-ranked clone bank grafts. Because of genetic variability among the unidentified pollen parents of each progeny and among the pollen grains or ovules produced by the wild parents of each progeny, it is likely that the genetically best trees in the first-cycle population are in the test plantations rather than in the clone bank. Family-test results, however, are less accurate in assessing test plantation trees than in assessing clone bank grafts, especially during early (5-10 yr) measurements. The possibility of additional genetic gain in the first cycle of improvement justifies some attempt to overcome this accuracy handicap by using later (15-30 yr) first-cycle measurements. Output materials will need to be obtained from selected individual trees in quantities sufficient for seed orchard establishment because their assembly in a clone bank would not be feasible.

Breeding Districts

The program covers the southern part of the forest zone from eastern Manitoba to western Saskatchewan, omitting an area of low productivity in central Manitoba. Due to the extent of this program area, progenies that are superior near their source are not likely to be superior in areas remote from their source. The program area therefore is divided into separate parts, and each progeny is tested only in the part that contains or is closest to its source. The parts are termed *breeding districts*, or simply *districts*.

Each district has one family test consisting of four replicated plantations on sites intended to be representative of the range of jack pine plantation habitats typical of that district. Clone bank grafts and test plantation trees will be rated on the premise that the best estimate of the progeny's productivity on any plantation habitat in the district is its mean for all plantations of its test. Attempts to infer superiority for part of a district from superior performance in one or two test plantations are unlikely to be productive (Wright 1976, p. 148-149).

Clone Bank

An applied breeding program requires some means of producing large quantities of planting stock that carries the genetic superiority of the selected genotypes. This program's first selection cycle includes a clone bank plantation (Libby 1973) intended to fulfill part of the function of large-scale production. When completed, this plantation will contain five grafts of the seed parent clone or of selected progeny trees for every tested family. Clone bank grafts selected according to family-test performance will provide scions for grafting or pollen and conelets for controlled pollination. Trees produced by these methods from the selected grafts will be used to establish operational seed orchards, which then will complete the transfer of genetic superiority to large-scale production of genetically improved jack pine seed.

Provision of a separate clone bank plantation allows its purpose to be fulfilled without compromising (or being compromised by) the different requirements of the genetic assessment and mass-production functions of the breeding program. Grafts for all tested families of

the three breeding districts are being assembled at one accessible site of above-average productivity. Cultural treatment can be varied among grafts of each family to promote production of either graftable scions or pollen and seed. These measures would be inconsistent with the genetic assessment function. Maintenance in the clone bank of grafts for all families allows prompt exploitation of changes in progeny ranking in the family tests. Some effort is thereby wasted on tending of nonsuperior grafts, but the value of materials obtained from genetically superior grafts is not affected by inferior neighbors. A seed orchard's effectiveness would be diluted by inclusion of genotypes that might or might not become superior at a later age.

The considerations outlined above could also apply to a plantation of sibs of family-test trees. Use of clonal material for genotype assembly and initial expansion was prompted by the expectation that parent clones or progeny grafts of the best progenies will be genetically superior to random sibs.

BREEDING DISTRICTS

Breeding districts were delineated in southeastern Manitoba, the uplands near the Manitoba-Saskatchewan boundary, and in a band of about two degrees latitude in width along the southern margin of the forest zone from central Saskatchewan to eastern Alberta. These general areas, designated as the eastern, central, and western breeding districts, contain a substantial amount of land suitable for planting of genetically improved jack pine. Breeding district boundaries shown in Figure 3 represent the limits of areas where planting of the respective improved populations will be recommended. These boundaries are subjective; the consequences of moving genotypes within breeding districts will be indicated by family-test results, and the consequences of moving genotypes beyond breeding district boundaries can be learned only by planting additional tests.

Eastern Breeding District

Most reforestation activity in southeastern Manitoba occurs in the Sandilands Provincial Forest, which is situated largely on a sandy end moraine upland and is roughly 600 km^2 in extent. Soils on this upland are predominantly rapidly drained and support a forest cover dominated by jack pine (Smith and Ehrlich 1964). The Belair Provincial Forest, further north, is a smaller area having similar physiography and vegetation. Between these provincial forests and east to the Ontario border the landscape is dominated by muskeg or by rocky terrain of the Precambrian Shield and includes some productive forest land on deposits of varying texture and drainage. The eastern breeding district extends to the Ontario and United States borders on the east and south and to agricultural land just west of the provincial forests. The northern limit is provisionally set at 51° N latitude. Sandilands and Woodridge Eluviated Eutric Brunisols on rapidly drained sandy morainic outwash or aeolian deposits and on calcareous sand and gravel deposits, respectively, are characteristic soil associations on the productive forest land in the eastern breeding district (Canada Soil Survey Committee, Subcommittee on Soil Classification 1978; Smith and Ehrlich 1964).

Central Breeding District

The central breeding district comprises the Duck Mountain, Porcupine Hills, and Pasquia Hills uplands together with adjacent forested lowlands. These uplands, originating as end moraines, have undulating to strongly rolling topography at elevations of 600-700 m, with a few summits of 750-800 m. They have moderately to steeply sloping escarpments on their north and east margins, leading to the Manitoba Lowlands physiographic region at about 300 m. The more gradual westward slopes lead to the slightly higher lowlands of the Manitoba-

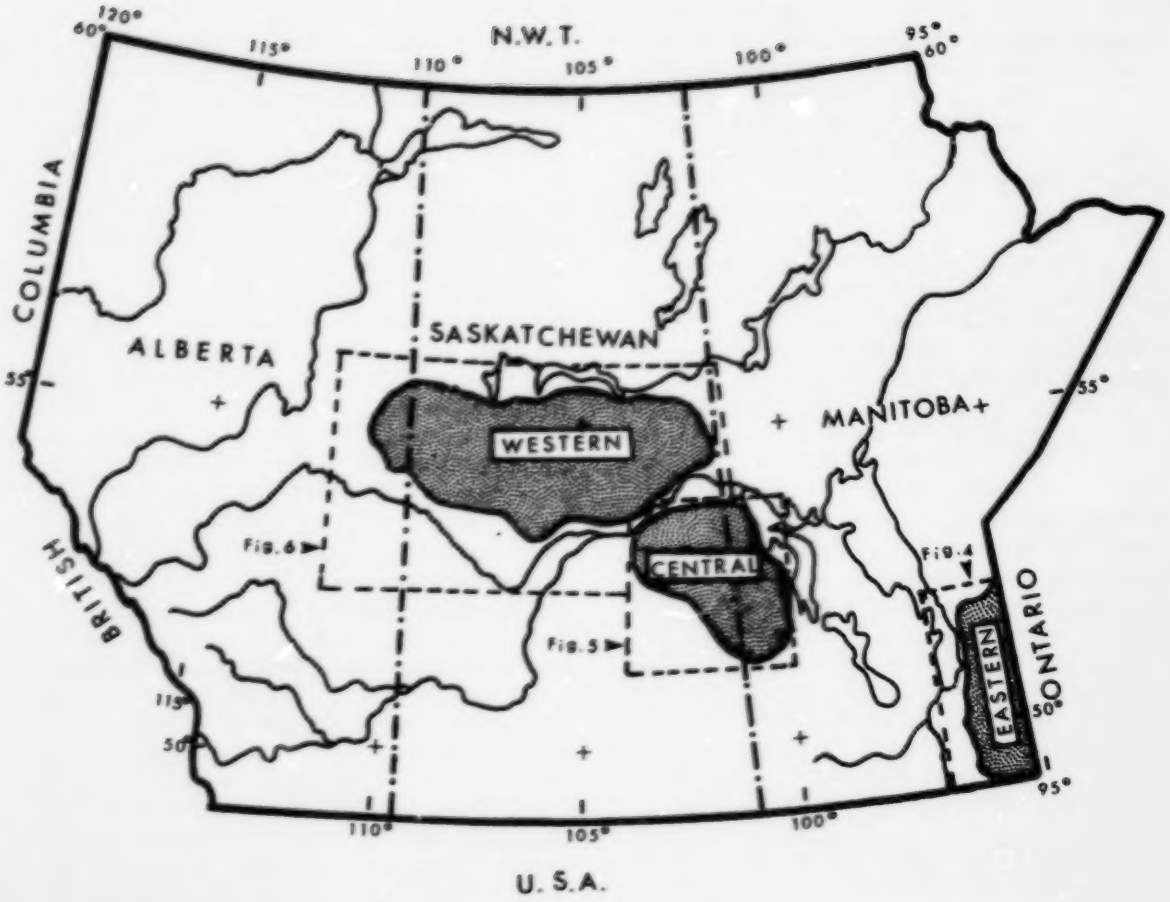

Figure 3. Breeding district boundaries.

Saskatchewan Lowlands and the Saskatchewan Plains physiographic regions (Kabzems et al. 1976). South-facing slopes are of intermediate steepness. Most of the breeding district's boundary is situated just above agricultural land or on extensive areas of organic deposits at elevations of 350-450 m.

Published information on soils and forest productivity in the breeding district is available only for the Pasquia Hills portion (Ayres et al. 1978). Soils information for the other uplands can only be inferred from soil survey reports for adjacent agricultural areas (Ehrlich et al. 1959, 1962). Surface deposits are predominantly glacial till, which may be unsorted, resorted, or eroded by water or modified by rock fragments. Stones are generally abundant in the deposits. Medium- to fine-textured soil parent materials dominate. At the higher elevations, numerous lakes and peat-filled depressions are mixed with rapidly drained slopes. In the Pasquia Hills, surface drainage is generally more moderate and forest productivity less severely limited on the escarpments than on the plateau.

Trembling aspen (*Populus tremuloides* Michx.) and white spruce are the dominant tree species on Duck Mountain and the western portion of Porcupine Hills, while black spruce (*Picea mariana* (Mill.) B.S.P.) is dominant in other parts of the breeding district. Jack pine occurs in pure stands on sandy soils and in mixture with black spruce.

Western Breeding District

The boundary of the Mixedwood Section (B.18a) of the Boreal Forest Region (Rowe 1972) is used as the boundary for the western breeding district, from the central district to western Saskatchewan, where the northern boundary is set at 55°30' N latitude. An adjacent area in eastern Alberta is included. Elevations as low as 305 m occur northwest of the Pasquia Hills in the Carrot River Lowlands section of the Manitoba-Saskatchewan Lowlands physiographic region, but productive forest soils are rare below 400 m. Elevations in excess of 700 m occur in the Waskesiu Hills and Wappaweka Hills sections of the Saskatchewan Plains region and in the Thickwood Hills Uplands of the Alberta High Plains region (Kabzems et al. 1976).

Soil survey reports have been published for three map areas in the western district, from 104° to 110° longitude and from 53° to 54° latitude (Anderson and Ellis 1976; Crosson et al. 1970; Rostad and Ellis 1972). Surface deposits on productive forest land west of 108° W longitude within the area are nearly all glacial till. The remainder of the area has roughly equal amounts of till and glacial meltwater deposits. The till is predominantly moderately coarse to moderately fine in texture, whereas the texture of the glaciofluvial, fluvial-lacustrine, and glaciolacustrine deposits is predominantly coarse to moderately coarse. Topography varies from level to strongly rolling, with roughly undulating landscapes covering the largest area. Level terrain within the forest areas is usually associated with unproductive organic soils. Characteristic soil associations on productive forest land are Loon River Orthic Gray Luvisols on medium- to fine-textured, weakly to moderately calcareous glacial till and Pine Eluviated Eutric Brunisols on weakly to noncalcareous coarse-textured fluvial-lacustrine deposits.

For the entire Mixedwood Section in Saskatchewan, standing volume is estimated at 66×10^6 m^3 for jack pine, 53×10^6 m^3 for white spruce, 47×10^6 m^3 for black spruce, and 120×10^6 m^3 for trembling aspen. Mean annual increment of fully-stocked jack pine stands at maturity varies from 0.8 m^3/ha on rapidly drained sand and gravel deposits to 3.2 m^3/ha on moderately fine-textured deposits (Kabzems et al. 1976).

BREEDING MATERIALS

Parent-tree selection and collection of cones and scions started November 1, 1967, and was completed in June 1975. Selection and collection were done for the eastern breeding district in November and December 1967, March 1968, and September 1969; for the western district in October to November 1968, November to December 1969, and November 1971; and for the central district in November to December 1970, December 1971, and June 1975. The work was done by two-person crews, except in 1971 and 1975, when it was done by a forest research technician working alone. Approximately 0.7 person-years were required to complete assembly of breeding materials.

Parent Trees

Locations of parent trees were chosen to obtain a representative sampling of wild breeding populations within each breeding district. In most locations, three parent trees were selected after careful inspection for good vigor and superior stem quality. Source-stand location and various parent-tree and source-stand characteristics were recorded. Cones and scions were collected at the time of parent-tree selection.

Parent-tree locations were chosen by observing the distribution of jack pine from public roads. In areas of abundant jack pine, mature, extensive, fully-stocked stands were chosen at intervals of 5-10 km. In other areas selection was done within groups of 20-50 cone-bearing trees, at similar or longer intervals. Because off-road vehicles were not used, jack pine stands distant from roads were not sampled. Sampling gaps are relatively large and numerous for the western district and are less important in the eastern district.

Parent trees were selected by visual examination and subjective judgment rather than by measurement and formal scoring. Traits favored were minimum severity and frequency of crooks, flat branch unions, absence of forks, and good vigor. Exceptional size was given little emphasis.

In stands of sufficient extent, three parent trees were selected. In a few central district stands, six parent trees were selected. Where jack pine occurred only in small groups, one or two trees were selected. The availability of test-plantation performance means for more than one progeny from most source locations allows selection of productive source populations for operational cone collections, as well as estimation of genetic variability within family-test progenies.

During the first season of parent-tree selection (November 1967 to March 1968) only location, age class, and stocking class of source stands were recorded. From September 1968, crown class of selected trees was estimated, then height, diameter, and age were determined after the trees were felled. Extent, stem quality, site, topography, and associated vegetation were also recorded for source stands. Estimated branch angle records for stands or selected trees were started in November 1970.

Parent trees were numbered in the order of their selection, starting with 1001 in the eastern district, 1301 in the central district, and 1601 in the western district. An accession list on file contains the recorded information for all parent trees.

Cones and Scions

Cones and scions were collected from all selected parent trees at the time of selection. Nearly all of the parent trees were felled for this purpose. Most parent trees provided 20-50 cones produced in several years and four or more scions. Vigorous 1-year-old shoots from the upper crown bearing an apparently sound terminal bud were cut to a length of roughly 10 cm. Tree-number labels were placed inside the cloth cone

bags and polythene scion bags. Portable coolers were used to chill the scions when required, but successful grafts were obtained from scions that became heated while being shipped by rail in November 1968. Scions were stored at 2-5°C or -18°C from their arrival at program headquarters until they were grafted.

ESTABLISHMENT OF FAMILY TESTS

Test establishment procedures are described in the following sections and in greater detail in one published family-test establishment report (Klein 1973) and two reports on file at the Northern Forest Research Centre[1,2].

Seed Extraction, Cleaning, and Storage

Procedures and equipment used to obtain clean, viable seed for family-test progenies were occasionally modified during the materials-assembly phase of the program. Some techniques were used only briefly, and not all were recorded.

Generally, seeds were extracted, cleaned, and placed in storage within a month of completion of a collection trip. Prior to 1970, cones were allowed to open on greenhouse benches following a hot-water dip at 55°C or were heated in a laboratory oven at various unrecorded temperatures. Cones collected from 1970 onward were heated at 40-45°C for 16-20 hours. Opened cones were tumbled for seed extraction in a rectangular drum with wire-mesh sides.

Seed wings were detached from the seeds by mild abrasion of dry seeds or, from 1970, by tumbling and warm-air aspiration of moistened seeds. Separation of clean seeds from the wing fragments produced by abrasion was done in an Office Clipper[3] seed cleaner or by manual agitation in a sieve following the aspiration treatment. Empty seeds were removed in a fanning mill[4]. After cleaning, all seed lots were dried by being allowed to reach equilibrium with circulating air at 26°C and 30% relative humidity in an incubator with a chemical dryer[5]. Seed moisture content after this treatment was 6% ± 1%, based on weight after 48 hours at 95°C.

From November 1967 to the winter of 1969-70, the seeds were stored in plastic vials, but these were found to admit moisture. Following redrying, the seeds were placed in 5-mL screw-capped glass vials. Mold was observed on some seed lots, but no serious loss of viability occurred. Storage temperature was 1° ± 1°C to October 1972 and from -7°C to -10°C afterward for better seed viability in long-term storage. The seed vials are currently arranged in trays in two cabinets in a cold room at the Northern Forest Research Centre. Cabinet doors, shelf edges, and trays are labeled with seed-lot family numbers to facilitate retrieval. A 1974 seed inventory is on file.

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[1] Klein, J.I. and A.M. Nanka. 1981. Establishment of jack pine family-test plantations in eastern Saskatchewan and western Manitoba, 1976. Environ. Can., Can. For. Serv., North. For. Res. Cent. Edmonton, Alberta. Unpublished file report.

[2] Nanka, A.M. and J.I. Klein. 1978. Establishment of jack pine family-test plantations in central and western Saskatchewan, 1974. Environ. Can., Can. For. Serv., North. For. Res. Cent. Edmonton, Alberta. Unpublished file report.

[3] A.T. Ferrell and Co., Saginaw, Michigan.

[4] Series 136, Model D, E.L. Erickson Products, Brookings, South Dakota.

[5] Model I24 DH, Controlled Environments Ltd., Winnipeg, Manitoba.

Rearing of Planting Stock

Eastern Breeding District

In October 1969, 226 eastern district progenies, 10 western district progenies, and 4 control lots were sown in sandy-textured soil in a five-replicate, randomized block design at Birds Hill Research Nursery near Oakbank, Manitoba. The control lots were stand collections originating in the Sandilands Provincial Forest and were provided by the Pineland Forest Nursery. Each plot was a half-row of 18 seed spots at 25-mm spacing, extending from each edge of the seedbed to the center. The number of seeds to be sown at each spot was determined by laboratory germination. Two-plot rows were spaced 150 mm apart along the seedbed. The spots were thinned to a single seedling following germination in 1970. Manual weeding, supplementary irrigation, and application of granular fertilizer were carried out during the 1970 and 1971 growing seasons.

The seedlings were lifted with shovels in April 1971. Pronounced variation in stocking and seedling size, apparent at the time of lifting, demonstrated the importance of replication during rearing. The seedlings from one plot were placed in a polythene bag with their nursery-plot label. The polythene bags were arranged on shelves in an unheated basement at 2°C at shelf positions marked with the progeny numbers. On May 4, following labeling and arrangement for planting, the seedlings were transferred in cartons to a cold room kept at 0°C.

Western Breeding District

Planting stock for the western and central district tests was reared in Rootrainer[6] seedling containers. One of these molded plastic containers forms a strip of cavities when folded and is unfolded to remove each seedling with its plug of rooting medium from the cavity in which it grew. Two sides of each cavity are vertically corrugated to prevent root circling.

Containers with four 50 x 50 x 200 mm cavities were used for the western district test. The rooting medium was sphagnum peat. One sowing plot consisted of four containers (16 cavities) seeded with one progeny or stand collection. There were four randomized sowing replicates. Sowing of 254 progenies and two stand collections (controls) of known western district origin was done in May and June 1973. Transplanting of doubles to blank cavities and removal of surplus seedlings occurred in June and July.

The containers were transferred from the greenhouse to a lathhouse in July and August. They were returned to the greenhouse in November and December for a second growth period. Greenhouse temperature was lowered gradually beginning in February 1974. On April 1 the heating system was drained and all vents were opened to provide a second chilling period. Soluble commercial fertilizers and supplementary illumination from cool-white fluorescent tubes were provided during the two growth periods.

Central Breeding District

Containers used for the central district test were the same type as those used in the western district test, but the four cavities in each container measured 40 x 40 x 100 mm. Sowing and rearing were done in three replicates. A sowing plot consisted of eight containers in one tray. Sowing of 244 progenies and two stand collections of known central district origin was done in June 1975. About 15 plots were sown in late July to replace plots that were either omitted or apparently duplicated in the June sowing. In June and July, duplicate seedlings were

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[6] Spencer-Lemaire Industries Ltd., Edmonton, Alberta.

transplanted into blank cavities, and seedlings with roots on the surface of the peat were replanted. The remaining duplicate seedlings were removed in July and August.

The seedlings were kept in the greenhouse until March 1976. Temperature and day length were maintained at levels suitable for active growth until November 1975 for the June sowing. There was a gradual reduction to short days and temperatures of 10-15°C by January 1976. The July-sown plots were held at long days and warm temperatures until March 1976. The supplementary illumination from cool-white fluorescent tubes allowed continuation of shoot initiation and development during fall and winter, although these shoots were abnormally short. Mineral nutrients were applied in various forms about biweekly from July to September, less frequently after that for the June sowing, and not at all after January 1976.

The trays of seedlings were transferred in mid-March to a cold room at 5°C, where they remained through April.

Statistical Design

The cubic lattice design was used for the family tests, as it was judged to be well suited for sensitive performance comparisons among a large number of progenies. Incomplete block designs improve precision in experiments with large numbers of treatments (Cochran and Cox 1960). The cubic lattice design is a type of incomplete block design developed for plant breeding trials. The procedure for design plan construction is described by Cochran and Cox (1960, p. 422-425).

The number of treatments must equal the cube of an integer if cubic lattice design is to be used. It was judged that family tests having 216 progenies and controls (blocks of six plots) would allow adequate interfamily selection while maintaining genetic diversity within the selected portion of the population. More than 216 progenies were assembled and reared for each breeding district to ensure that the requisite number would be available in the event that some were unusable. All three tests have four-tree row plots. There are four sets of replicates in the western and central district tests and five in the eastern district test. One eastern district plantation has two sets of replicates, and the other plantations each have one set.

Design Plans

A randomized design was planned for each replicate of every test. The design plans were used to set up permanent observation record forms and plantation layout diagrams for the test plantations. The forms are on 40-line, 80-column sheets, with a separate line for identification and performance observations of each tree. Replicate, block, progeny code, and tree-in-plot numbers were entered at the left side of the forms in the sequence indicated by the design plans. The sheets were bound in 15 replicate-set books. Plantation layout diagrams are bound in the performance record books and are included in the family-test establishment reports. (The diagrams in the eastern district report (Klein 1973) have the plot sequence inadvertently reversed within blocks.)

Selection of Progenies

The number of plantable seedlings was an important factor in selection of progenies for the eastern and western district family-test plantations. Following lifting, only 209 eastern district progenies had the requisite number of seedlings for 15 plantation replicates. Six other progenies selected on the basis of a count prior to lifting had to be replaced by western district progenies. The control lot for the eastern district test had seedlings from two of the stand collections. Most of the progenies in the western district test were selected following a germination count of the first two sowing replicates. A few were selected later to replace progenies in which shortages appeared. Source distribution was considered in the initial selection of progenies. All of the central

district progenies provided enough seedlings for the test design. Most of the 30 progenies omitted had relatively short parent trees. Both stand collections from the western and central districts were selected.

Progenies selected for use in a test were assigned the 216 code numbers at random. Progeny labeling showing both code and accession numbers in various formats was used for rearrangement of seedlings from the sowing design into the plantation design. Family-test seed-lot origin lists presented in the establishment reports and family performance record forms show both identification numbers, with families listed by code number. Family performance record forms, providing one 80-column line for each family, have source data and space for entry of progeny means from periodic family-test measurements. Design plans, observation record forms, plantation layout diagrams, and plantation plot labels used the code numbers alone.

Arrangement of Planting Stock into Plantation Design

Plot bundles for the eastern district test were formed to promote random mixing of nursery replicates in plantation plots. There was no culling except of damaged seedlings, and a few plot bundles were short one seedling. Roots were pruned and dipped in water, and the 15 plot-bundles of each progeny were then returned to storage in one polythene bag. Plot bundle labels marked with progeny, plot, block, and replicate numbers were arranged prior to lifting so that they were dispensed in the plot sequence prescribed by the design plan. Each label in turn was attached to a plot bundle removed from the polythene bag for the progeny indicated on the label. The labeled plot bundles were bound by blocks and packed by replicates.

Labeling of the plot bundles during arrangement into the planting design rather than during their formation saved time but allowed errors of progeny identification to occur undetected. As a result of this unforeseen weakness in the procedure, 23 progenies were short 1 or, in two instances, 2 plot bundles, and 25 progenies have seedlings of a different unidentified progeny in 1 or, in one instance, 2 of their 15 plots. Container-grown seedlings of the appropriate progeny were planted in June 1973 in plots left blank by the shortages. Progenies having 1 or 2 plots of different progeny are liable to a slight error (one-fifteenth of the difference in progeny effect between the intended and substituted progenies for each substituted plot) in the measurement of their mean performance.

For the central and western district tests, one four-cavity container held the seedlings for one four-tree plantation plot. Extra containers were sown for each progeny to allow filling of unstocked cavities or replacement of cull seedlings by transfer of rooting medium plugs between containers. The ratio of extra containers to plantation plot containers was barely adequate for the western district test (1:3). It was increased for the central district test (1:1) to allow selection of premium seedlings.

To prepare for formation of plantation blocks and replicates for the western and central district tests, plantation plot containers from each sowing replicate were arranged in sequence of progeny code number. The design plan for each plantation replicate was then used to identify the six progenies to be assembled for each block of that replicate and to arrange their containers in the prescribed plot sequence in each block. Blocks were arranged and kept by plantation replicate and block number sequence from the time of their formation, which was during the first growth period for the western district test and at the end of the rearing period for the central district test.

In each western district sowing replicate, the three plantation plot containers from each progeny were allotted to the three replicates of one plantation. Any effects of environmental differences among sowing replicates will consequently contribute an upward bias to

estimates of plantation effects and plantation-by-progeny interactions in the western district test results. For the central district test, each of the four containers from every tray of a sowing replicate was allotted to a different plantation (replicate set), so each plantation has one container from every tray. Sowing replicate environmental effects for the central district test will thus be included more appropriately in intraplantation experimental error.

Plantation Layout

Apart from spacing between trees, plantation layout within replicates is the same for all three tests. The four trees of one plot are in a row along a furrow. The six plots of a block are in adjacent furrows, with their four tree positions aligned perpendicular to the furrows. The 36 blocks of a replicate are arranged in 6 columns, each with 6 blocks. Blocks in a column occupy the same six furrows and are numbered consecutively, always from the same end of the column. From the low-numbered to the high-numbered end of a column, block numbers increase by six, and plot numbers within blocks increase consecutively from right to left. Trees in plots are numbered in the same direction as blocks in columns.

All but two of the plantations consist of one cubic lattice set of three replicates, joining at block column ends. One eastern district plantation has two replicate sets, joined at block column sides, and one central district plantation has one replicate separated from the other two by a few hundred metres. Two rows of jack pine surround these two parts and the three or six replicates of the other plantations. There are no other border or buffer rows. Replicate sets were randomly assigned to locations for the western and central district tests. Replicates in sets were randomly assigned to replicate positions in plantations for all tests.

Test Site Description and Preparation

Four planting sites were selected for each test during the summer prior to planting. Location, physiography, and soils are described in Tables 1, 2, and 3, along with climatic parameter estimates interpolated from maps in Chapman and Brown (1966). Soil descriptions, based on field inspection and laboratory analysis of soil pits in the test plantations, follow terminology of the Canada Soil Survey Committee, Subcommittee on Soil Classification (1978). Detailed site and soil descriptions, test plantation access maps, and plantation layout diagrams are presented in the family-test establishment reports mentioned earlier. Location of test sites and progeny source stands are shown in Figures 4, 5, and 6 for the three breeding districts.

The test sites are reasonably representative of the range of sites presumed to be available for planting of jack pine in the three breeding districts. Except for the eastern district's Site 4, which has a moderate number of boulders, the sites are generally free of large stones. The coarse soil texture of all the eastern district sites typifies the area. Some areas covered by similar deposits are less rapidly drained, and the test might have been enhanced by inclusion of at least one such site. One of the three major uplands in the central district, the Pasquia Hills, is represented by a test site on an adjacent lowland area that is typical of the relatively productive sites along the margin of the upland. The Porcupine Mountain and Duck Mountain sites are on the uplands. Test-site soil textures range from medium to very fine, varying within and among sites. Coarse-textured soils are of minor importance in this breeding district. Two of the western district sites are on coarse-textured outwash near the southern boundary of Nipawin Provincial Park, and two other sites are on medium-textured glacial till north of Glaslyn. The northern portion of the district is not represented.

Eastern District Test sites 1 and 2, situated in an area reserved for research use by the Canadian Forestry Service, had only scattered trees as a result of periodic fires. The other test sites were within recent timber sale areas. Jack pine had been the dominant species before cutting

Table 1. Characteristics of family-test plantation sites in the eastern district

Characteristic	Site 1	2	3	4
LOCATION				
Province	- - - - - - - - - - - - Manitoba - - - - - - - - - - - -			
Town	- - - - - Sundown - - -		Marchand	Stead
N latitude	49°13'	49°13'	49°28'	50°28'
W longitude	96°20'	96°20'	96°09'	96°25'
Elevation, m	330	325	345	280
Township-range	3-9	3-9	6-10	17-8
PHYSIOGRAPHY				
Physiographic area	- - - - - - - - - Bedford Hills - - - - - -			Unknown
Surface deposit	- - - - - - - - - End moraine - - - - - - - - -			Unknown
SOIL				
Subgroup	- - - - - - - - - Orthic Eutric Brunisol - - - - - - - - -			
Dominant texture	- - - - - - - - - - - - - Sand - - - - - - - - - - - - - -			
Estimated drainage	- - - - - - - - - - -Rapidly drained - - - - - - - - - - - -			
Association	- - - - - - Sandilands-Woodridge - - - -			Unknown
CLIMATE				
Mean temp., °C				
July	19	19	19	20
January	-17	-17	-17	-19
Degree-days above 5°C	1500	1500	1500	1500
Frost-free period, 0°C days	90	90	90	120
Mean precip., mm				
annual	530	530	530	500
May-Sept.	330	330	330	300

Table 2. Characteristics of family-test plantation sites in the central district

Characteristic	Site 1	Site 2	Site 3	Site 4
LOCATION				
Province	- - - Saskatchewan - - -		- - - Manitoba - - - -	
Town	Smoky Burn	Swan Plain	Birch River	Boggy Creek
N latitude	58°31'	52°18'	52°28'	51°33'
W longitude	102°25'	102°05'	101°17'	100°58'
Elevation, m	350	550	690	700
Township-range	52-3	38-1	40-27	30-25
PHYSIOGRAPHY				
Physiographic area	Pasquia Beaches	Porcupine Escarpment	Porcupine Mountain	Duck Mountain
Surface deposit	Colluvial	- - - - - - Ground moraine - - - - - - - -		
SOIL				
Subgroup	Orthic Regosol-Rego Dark Gray	Dark gray Luvisol	Brunisolic Gray Luvisol-Orthic Gray Luvisol	Orthic Gray Luvisol
Dominant texture	Clay loam	Clay loam	Sandy Clay loam and heavy clay	Clay to heavy clay
Estimated drainage	- - - - - - - Moderately well drained - - - - - - - - - -			
Association	Nitenai	Unknown	Unknown	Duck Mtn.
CLIMATE				
Mean temp., °C				
July	18	17	18	18
January	-20	-20	-20	-19
Degree-days above 5°C	1150	1100	1100	1100
Frost-free period, 0°C days	90	70	70	70
Mean precip., mm				
Annual	460	460	480	500
May-Sept.	290	300	300	300

Table 3. Characteristics of family-test plantation sites in the western district

Characteristics	Site 1	Site 2	Site 3	Site 4
LOCATION				
Province	- - - - - - - - - - Saskatchewan - - - - - - - - - - - -			
Town	- - - - -Snowden - - - -		- - - - Glaslyn- - - -	
N latitude	53°51'	53°52'	53°39'	53°46'
W longitude	104°38'	104°38'	108°19'	108°22'
Elevation, m	510	510	755	670
Township-range	56-18	56-18	54-16	55-17
PHYSIOGRAPHY				
Physiographic area	Lower Torch River Plain		- Thickwood Hills - - -	
Surface deposit	- - - Glacio-fluvial - - -		- Ground moraine - - -	
SOIL				
Subgroup	Eluviated Eutric Brunisol		-Orthic Gray Luvisol-	
Dominant texture	Sand	Loamy sand	Sandy clay loam	
Estimated drainage	- - - Rapidly drained - -		Moderately well drained	
Association	- - - - Kewanoke - - - -		- - Loon River - - -	
CLIMATE				
Mean temp., °C				
July	16	16	18	18
January	-20	-20	-19	-19
Degree-days above 5°C	1100	1100	1050	1050
Frost-free period, 0°C days	70	70	70	70
Mean precip., mm				
Annual	420	420	400	400
May-Sept.	280	280	260	260

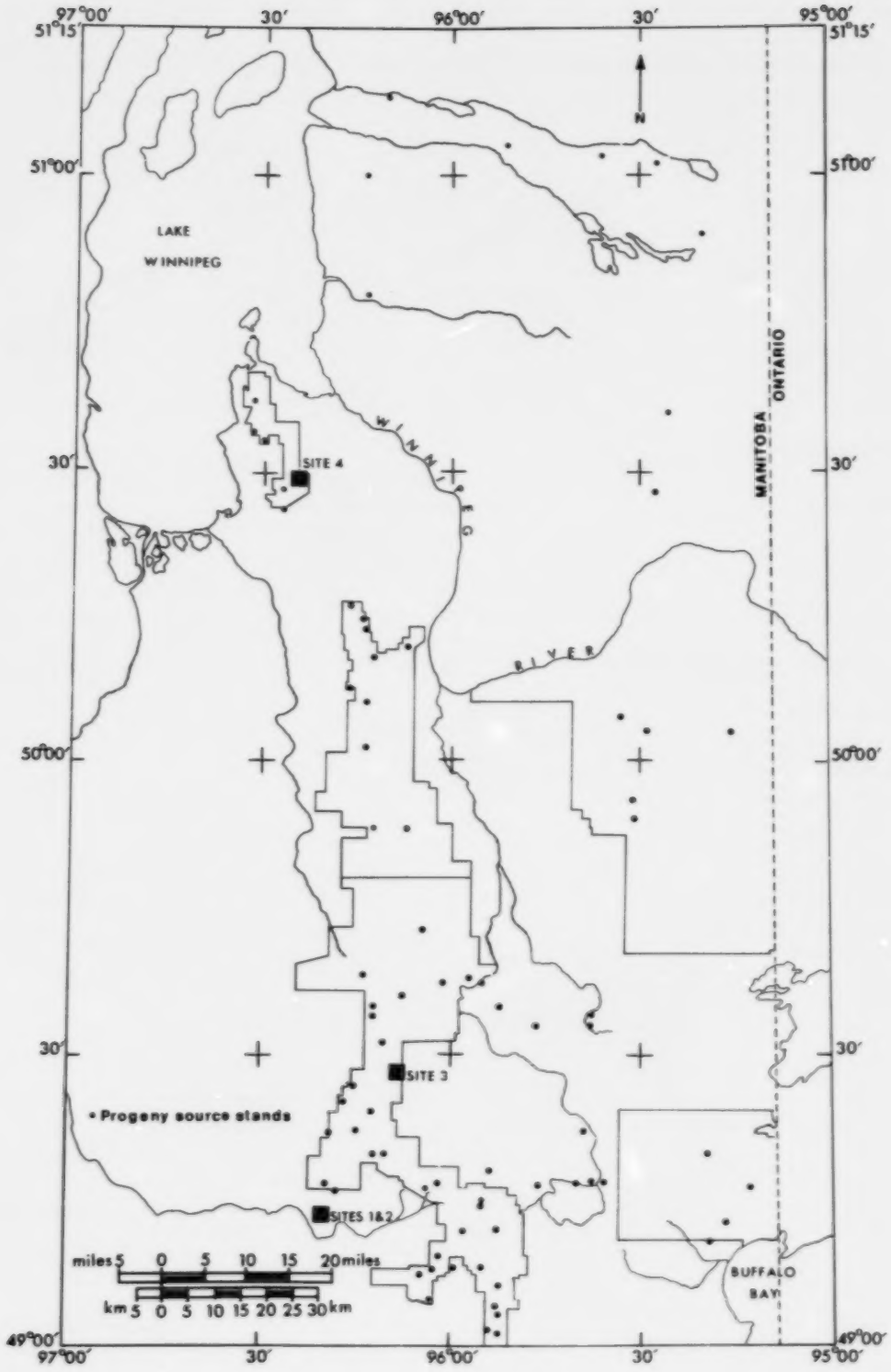

Figure 4. Location of planting sites and source stands, eastern breeding district family test.

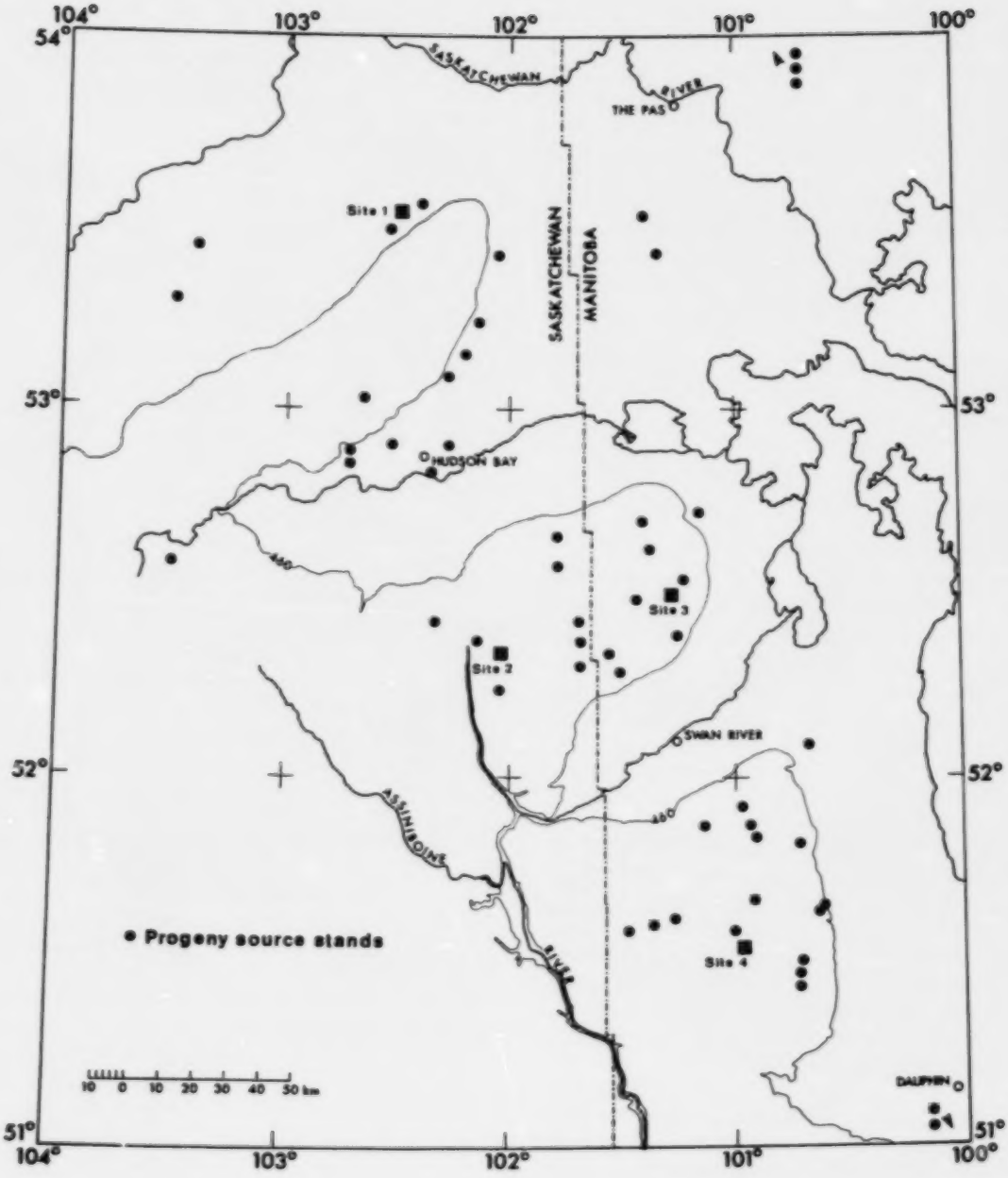

Figure 5. Location of planting sites and source stands, central breeding district family test.

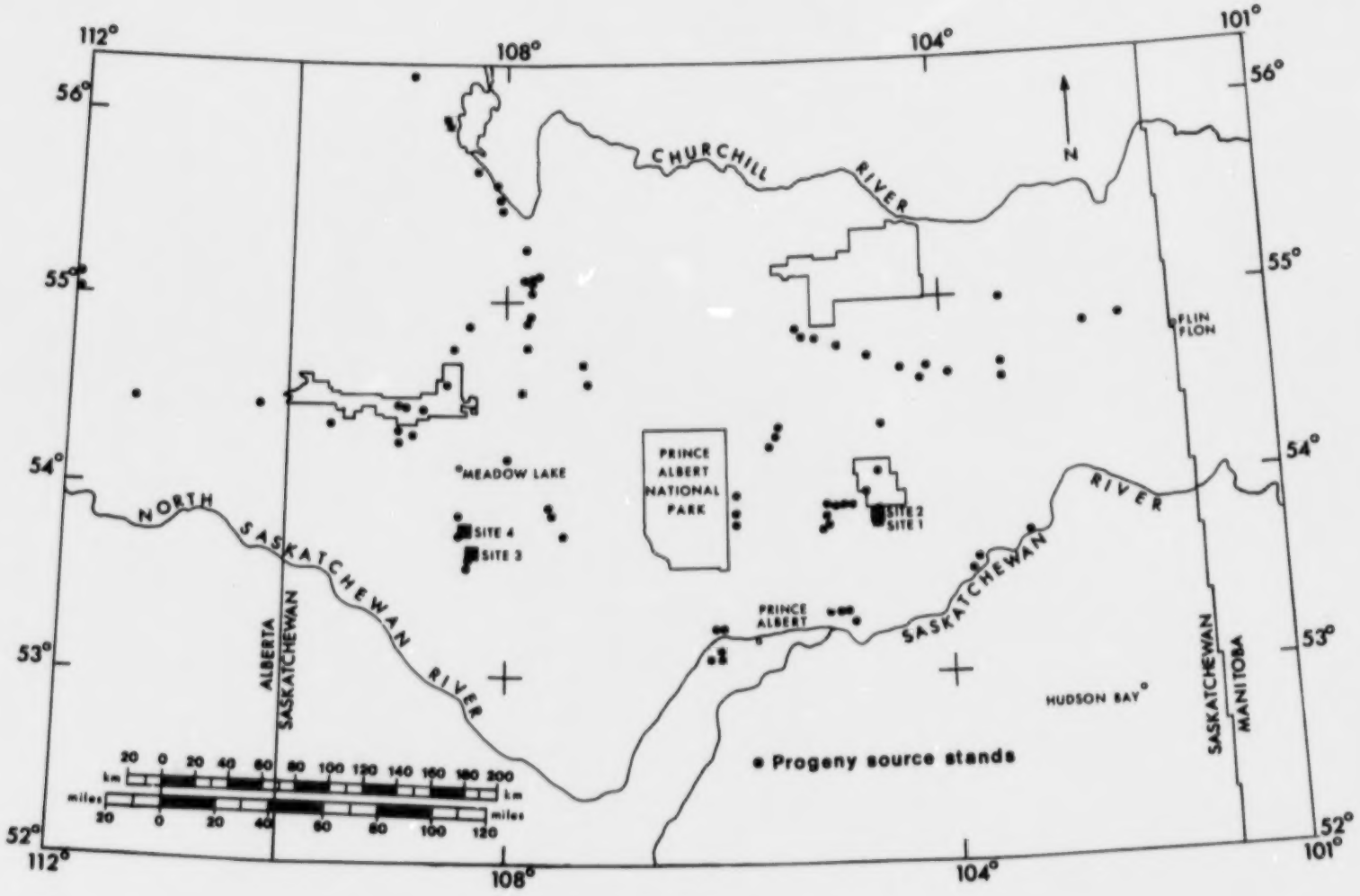

Figure 6. Location of planting sites and source stands, western breeding district family test.

except on three of the central district sites, where trembling aspen, white spruce, and paper birch were major stand components. Residual trees were removed from the sites after being cut or uprooted. The eastern district's sites 3 and 4 are on areas that had received prescribed burns following timber harvest.

Furrows were formed using tractor-drawn, finned barrels in various configurations on all eastern and western district sites. Finned barrels and anchor chains were used on three central district sites, and anchor chains alone were used on Central District Site 3. Scarification of the eastern district's sites 3 and 4 was done prior to their selection. The other sites were cleared and scarified by contractors or provincial government agencies. Forty furrows are required to accommodate one set of three contiguous replicates with a two-row border. At Central District Site 3 there was not enough room to fit three replicates in one place, so two sets of shorter furrows were prepared, with two replicates in one set and one in the other. The two replicate sets at Eastern District Site 4 required 76 furrows. Furrow length and spacing were set for tree spacing of 1.8 m for the eastern district test and 2.5 m for the other two districts' tests. Furrows were generally straight, continuous, parallel, and of reasonably uniform depth, except at Eastern District Site 4, where some furrows converge or become indistinct.

Plantation Establishment

Marking of Planting Positions

Temporary markers were used to control alignment and spacing of the planted trees for the eastern district test. Wire plot stakes bearing aluminum progeny code number labels were placed at the first tree of every plot about a year later. Plot labels of the same type as well as shorter unlabeled wire stakes for the other planting positions were placed in the western and central district plantations prior to planting. Block or replicate numbers or boundaries were not labeled or marked in the plantations.

Storage, Transportation, and Distribution of Planting Stock

Eastern district seedlings were in cold storage for 4-6 weeks from lifting to planting, including the period of arrangement into the planting design. On arrival at a planting site, the seedlings were heeled-in under shade and watered. Seedling roots were covered with water or wet peat after removal from heeling-in and until planting. Block and plot numbers on every plot bundle label guided arrangement of planting stock within replicates for heeling-in, removal from heeling-in of block bundles for each column of blocks, selection of block bundles in sequence along a block column, and matching of plot bundles to plantation plots. Conformity to the design plan was verified, and trees planted in the wrong plot were replanted in the prescribed plot on the same day as they were first planted.

Containers for the western and central district tests were transported under cover. Central district seedlings sown in July 1975 showed signs of low-temperature injury when they were unloaded, indicating that their rearing regime (in contrast to that of the June 1975 sowing) had failed to induce development of cold-hardiness. The containers were stored outdoors under shade for up to 10 days for the western district test and up to 5 weeks for the central district test. The central district seedlings were watered as required during outdoor storage in a prepared facility in western Manitoba. All plugs were moist when planted. Distribution of containers to planting sites and plots was done by matching progeny numbers on the embossed aluminum plot labels with those on the containers. The order of seedlings in the containers was maintained in the plantation plots so that a preplanting height measurement forms part of the permanent performance record on individual trees.

Planting and Maintenance

The forest genetics research technician supervised planting of all three family tests (including care of planting stock during transportation and distribution, instruction, and correction of planting technique) and ensured conformity of tree placement with design plans. A second forest research technician assisted with transportation and distribution of planting stock for the central district test. Planting crews were local residents or correctional center inmates. The seedlings were planted in holes dug with planting shovels. Planting generally proceeded in order of block number, beginning with the replicate containing Block 1 at an outside corner of the plantation. Border rows, containing trees sown for the test but not selected for use as plot trees, were planted before the plot trees at each plantation in order to outline the plantation and train the planting crews.

In anticipation of mortality in central district plots planted with seedlings sown in July 1975, replacement seedlings were sown in February 1978. Following three growth periods separated by two chilling periods, the few replacement trees actually required (by that time growing in 20 x 20 cm pots) were planted in July 1979.

All test plantations except the eastern district's sites 3 and 4 were fenced to keep out rabbits. Aluminum devices designed to flutter at low wind speed were attached to the western and central district fences in 1979, with the aim of reducing fence damage by wildlife. A fire guard 4 m wide was cleared around each western and central district plantation. Control of competing vegetation was carried out from 1978 to 1981 in all plantations except the eastern district's sites 1, 2, and 3, which did not require treatment. Volunteer pine seedlings were pulled. Other trees and brush were cut using a tractor-drawn brush mower, a brush saw, and hand tools.

CLONE BANK

Graft Production Methods

Understocks

All grafting for this program has been on potted jack pine understocks. Round, black vinyl pots are used that are 175 mm tall and 150 mm in diameter, have a 2.5-L capacity, and have four drainage holes that extend 20 mm from the bottom. Peat has been used as the rooting medium since 1975, and mineral nutrients are applied by use of soluble fertilizers.

Understocks of good size and condition have been produced by sowing in containers in spring, potting the following spring after outdoor wintering, and then leaving the pots outdoors in autumn until required for grafting. Because this procedure has required an excessive amount of time, the use of bare-root nursery stock grown for one summer after potting was resumed in 1982.

Scion Collection and Handling

Scions collected from November to March can usually be successfully grafted following frozen storage for up to several months, but unusually warm weather in March may reduce scion tolerance of frozen storage. Scions collected in April or May have been successfully grafted within a few weeks of collection when they were stored at temperatures near freezing; however, they may not survive longer or colder storage periods. Scions are cut to a length of roughly 10 cm for collection, packed dry in polythene bags, and chilled in portable coolers if necessary.

Grafting Technique

For scions of medium to large diameter (4-6 mm), understock stem sections of equal or slightly greater diameter are preferred. Stem sections of approximately the same diameter as the thinnest scions (3 mm) are too fragile for understock use. Scions with less than 4 cm in length in the previous year's shoot are difficult to graft successfully. Shoot length in excess of 6-7 cm is trimmed off. Needles are removed to 1-2 cm below the scion bud and from the selected understock stem section. Understock needles and branches may be bound away from the grafting point before the understock cut is made and released after the graft is bound.

For side-veneer grafting the scion is cut for a length of 2-4 cm on the side that is to face the understock and for a length of about 5 mm on the opposite side. Placing the long cut on the concave side of a curving scion promotes upright growth. The longer cut is made by sloping inward from the surface of the scion close to the lowest remaining needle bundles, entering the wood about 5-10 mm from the distal end of the cut, and removing a thin slice of wood from that point to the basal end of the scion. Failure to remove wood along most of the lower portion of the cut or exposure of the pith on the cut surface can reduce graft success. The importance of cut depth has not been otherwise determined. The shorter scion cut intersects the longer cut at the basal end of the scion to form a sharp edge perpendicular to the scion axis. Corresponding cuts are made on the understock, with the short understock cut forming a flap of a tongue of wood to support the basal end of the scion. The longer understock cut may be relatively shallow to match a thin scion, but must remove wood. Rubber strips are used to bind the grafts. The grafting technique is illustrated in Figure 7.

Daily output for an experienced worker ranges from 40 to 60 grafts.

Postgrafting Care

Grafts are kept in the greenhouse under intermittent mist for about 2 months following grafting. Successful grafts are then left under ambient greenhouse conditions or moved outdoors. Gradual removal of understock crowns begins during the year of grafting. The main understock stem is cut off some distance above the union. All understock branches directly over the scion are removed and long understock branches are shortened.

Successful grafts not planted in the year of grafting are wintered outdoors. There have been winter losses due to freezing, drying, and rodent feeding. A combination of fall spraying with an antidessicant, mulching with wood shavings, and enclosure of the grafts with snow fencing appears to provide ample protection from climatic damage. Rodent damage is minimized by repellant spray, trapping, and poisoned-bait feeder stations.

Grafting Results

Records have been kept of the number and success of grafts by clone for each year from 1975. The number and percentage of seed parent clones with high, medium, and low success rates are shown in Table 4. Of 590 eastern district family-test trees that have been grafted at the age of 8-11 years from seed, 76 (13%) have yielded no successful grafts in roughly 10 tries.

The average success rate for 1981 grafting, including a small proportion of family-test trees as well as seed-parent clones, was 90% for highly successful clones and 67% for moderately successful clones. The average success rate of clones that were grafted in 1981 was 76% for highly successful clones and 29% for moderately successful clones. These percentages are based on total numbers of successful grafts, not on summations of percentages for individual clones. Tech-

Figure 7. A jack pine graft.

Table 4. Grafting success rate of seed parent clones, 1975–81

	Success rate class			
	High (50%+)	Medium (10–49%)	Low (0–9%)	Total
Number of clones	395	46	34	475
Percent of clones	83	10	7	100

niques used in 1981 provide satisfactory to excellent success rates for roughly 90% of the clones established in preliminary clone banks. In 1982, success rates as high as 100% for 10 grafts were achieved with some clones that had yielded no success in 40 or more tries between 1975 and 1981. This result is tentatively attributed to collection of 20-30 cm branches, from which 10-cm scions were cut at the time of grafting. Further trials are needed to confirm this finding.

Preliminary Clone Banks

Preliminary clone banks were used until a permanent clone bank site was available.

The eastern district grafts, grafted in 1967 and 1968, were planted in the summer of 1969 at Birds Hill Research Nursery, about 25 km northwest of Winnipeg. The grafts were arranged by family number in a single row and spaced 0.3 m apart. Understock crowns were pruned off over several years. Some grafts died without yielding good scions for regrafting. Inventory and measurement of the grafts were done in 1971, 1973, 1974, and 1977. In April 1977 there were 92 surviving clones, with 162 grafts at an average height of 1.8 m. Secondary grafts produced with scions collected in this planting from 1975 to 1982 have been or will be planted in the permanent clone bank, and in 1980 scions were collected and grafted for establishment of an operational seed orchard.

In 1971 the Alberta Forest Service provided a site for another preliminary clone bank 2 km east of Whitecourt, on a sandy bench between a ridge and treed muskeg. Western and central district grafts produced from 1969 to 1972 were planted there in 1971 and 1972 at 0.9-m spacing. A perimeter fence was erected in 1971. Grafts are generally arranged by family number within year of grafting. In the fall of 1974, brush was cut, volunteer lodgepole pine (*Pinus contorta* var. *latifolia* Engelm.) seedlings were pulled, understock shoots were pruned, and the grafts were inventoried and measured. These treatments were repeated in the summer of 1979, surplus grafts were removed to reduce crowding, and tall grafts were topped at about 2 m. Granular fertilizer was broadcast around each graft in the spring of 1975. The 1979 inventory showed 940 grafts remaining in 394 clones. There were 292 grafts at least 2 m tall. Scions have been collected in this preliminary clone bank for clone bank grafting since 1974 and for seed orchard grafting in 1979 and 1980. Some grafts were transplanted to the permanent clone bank in 1980, 1981, and 1982. By the summer of 1981 there were only two clones at Whitecourt and none at Birds Hill that did not have any grafts in the permanent clone bank or in pots. A limited amount of scion collection is still required in the preliminary clone banks.

Progeny Ortets

Of the 637 families included in the family tests, 165-185 will eventually have grafts of selected progeny trees in the clone bank, in place of parent-clone grafts. There are no surviving parent-clone grafts for 118 eastern district families, 39 western district families, and 8 central district families. All ramets of four clones show yellow needles and scion overgrowth, suggesting incompatibility between scion and understock. Other parent clones could be lost to graft mortality before or after planting.

Grafting of eastern district progeny trees has been done annually since 1978. On the basis of superior height at 5 years from planting, five test-plantation trees were selected as ortets in each of 118 families. Successful grafts were obtained in 1982 from 5 or 6 selected progeny ortets of 67 western and central district families, including some with weak parent clones.

The Clone Bank Plantation

The permanent clone bank (hereafter referred to as the clone bank) is located in the Chip Lake Research

Planting Area near Wildwood, Alberta. This area is at 53°32' N latitude, 115°30' W longitude, and an elevation of approximately 880 m. The area is reserved by the Lands Branch of Alberta Energy and Natural Resources for CFS research. Growing-season climate is slightly cooler and more humid and the winters are slightly milder than is typical of the breeding program areas in Saskatchewan and Manitoba. The forest cover is predominantly trembling aspen and white spruce, with a minor component of lodgepole pine. Soils in the clone bank plantation are primarily moderately well-drained Orthic Gray Luvisols developed on fine-textured till overlain by about 10 cm of silt loam of uncertain origin. Weathered sandstone has been encountered at a depth of about 1.5 m. The plantation is on gently sloping terrain.

Clearing of two neighboring sites was done from October 1976 to March 1977. Trees of merchantable size were felled and skidded to landings for limbing and bucking. Logging slash, small trees, brush, and some of the stumps were chopped and scattered, but no scarification was done. The remaining stumps were cut at ground level and removed in 1979 and 1980, 2-3 years after planting of grafts began.

The plantation design accommodates five grafts for each of the 637 tested families: two on Site 1, on the south side of a ridge, and three on Site 2, on the north side of the same ridge. The plantation was divided because a single suitable area could not be found; division of each family's grafts into the two sites provides protection against localized mortality. Plots are arranged by family accession number at 3-m spacing. Two border rows of jack pine protect the outer planting positions on each site. Location maps and layout diagrams are presented in a report on file at the Northern Forest Research Centre[7].

Planting started in June 1977. More than 2200 ramets grafted from 1974 to 1978 and most of the required border trees were planted by October 1978. Planting in 1979 was limited to the correction of placement errors and improper planting in previous years and the utilization of extra ramets originally planted in border rows. In 1980-1982, 380 grafts were planted, including 110 grafts transplanted from the Whitecourt preliminary clone bank.

Stocking and graft development have been tallied at the end of each growing season since 1977. This tally is recorded on a form that provides one 80-digit line for each of the 3185 grafts required to complete the clone bank plantation. In September 1982, 2130 ramets were in satisfactory condition, and about 400 had died after being planted. Grafts now in pots or lined out will add about 930 stocked positions, leaving about 125 additional grafts required to complete the clone bank.

The clone bank is protected by a fence and a fire guard. Weed control and other tending are conducted annually.

APPLICATION OF EARLY RESULTS

Survival and height were first recorded for the eastern district family test following the second growing season after planting. The seedlings for the other two tests were measured in their containers at the end of the rearing period. These data will be used to determine mortality after the second year or

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[7] Klein, J.I. 1980. Acquisition and initial development of the Chip Lake Research Planting Area near Wildwood, Alberta. Environ. Can., Can. For. Serv., North. For. Res. Cent. Edmonton, Alberta. Unpublished file report.

after planting and as covariates for interpretation of later results.

Height measurements following the fifth growing season after planting have been taken for all three tests. Progeny height means were used to select parent clones for production of seed orchard grafts and to choose ortets from families lacking a parent clone. Eastern-district results were also used for assessing the prospects for selection of superior source areas.

Eastern Breeding District

Survival at 5 years from planting was above 90% for two plantations and 64% and 68% for the others. Plantation mean height varied from 67 cm to 78 cm, with a grand mean of 75 cm. Mean height was 70 cm for the control lot and 84 cm for the 20 tallest progenies, 12% above the test mean.

Progeny means and analysis of variance over all plantations were computed from unadjusted individual tree heights regardless of plots, incomplete blocks, replicates, and plantations. The one-way analysis of variance indicated that variation among progeny means was significant at the 99% confidence level. The standard error of a progeny mean was 3.3 cm, or 4.4% of the test mean.

Grafting for an eastern district seed orchard was done in 1980 and 1982 at the Province of Manitoba's Pineland Forest Nursery. A total of 360 scions of 38 selected families were grafted. Mean height of the selected families was 82 cm (109% of the test mean). Only 23 families with parent clones were grafted in 1980, but in 1982 scions were available from progeny grafts as well. The success rate was 53% in 1980 and above 90% in 1982. Grafts of the 15 families that remained superior according to the 10-year measurement will be included in a seed orchard scheduled for planting at the nursery in 1983. Results of the 10-year measurement will be reported later.

In using the 5-year height for within-family selection of progeny ortets, statistical adjustment of tree heights for site effects was obtained only at the level of replicate sets, not at the replicate and block levels. Reduction of the effect of within-replicate-set site variation was attempted by considering only the tallest tree on any plot for selection. Consequently, the five trees selected in any family must be the tallest from five different plots.

Source stand means computed from progeny means and expressed as percentages of the test mean were plotted on a map for selection of genetically superior seed source areas (Fig. 8). Three source areas had several stand height means close to 5% above average. These areas are located within Sandilands Provincial Forest in the southwestern portion of the breeding district and are centered at about 49°09', 49°15', and 49°35' N latitude. Most routine jack pine seed collection for planting in the eastern district is carried out in this general area. Limiting seed collection to the indicated locations will maintain or improve plantation productivity.

Western Breeding District

At 5 years from planting, the western breeding district family test was superior in survival (97%) and mean height (138 cm) to the eastern district test. Cubic lattice analysis was performed for all four plantations, each containing one set of replicates. Progeny means (adjusted for block effects) were computed for each plantation and were used to compute progeny means across locations. A two-way analysis of variance for all locations, based on progeny-in-plantation means, indicated that progeny means varied significantly at the 99% confidence level. The standard error of a progeny mean was 4.6 cm, or 3.3% of the test mean. Mean height of the 20 tallest progenies was 151 cm, 9% above the test mean. The two control lots had mean heights of 133 cm and 142 cm.

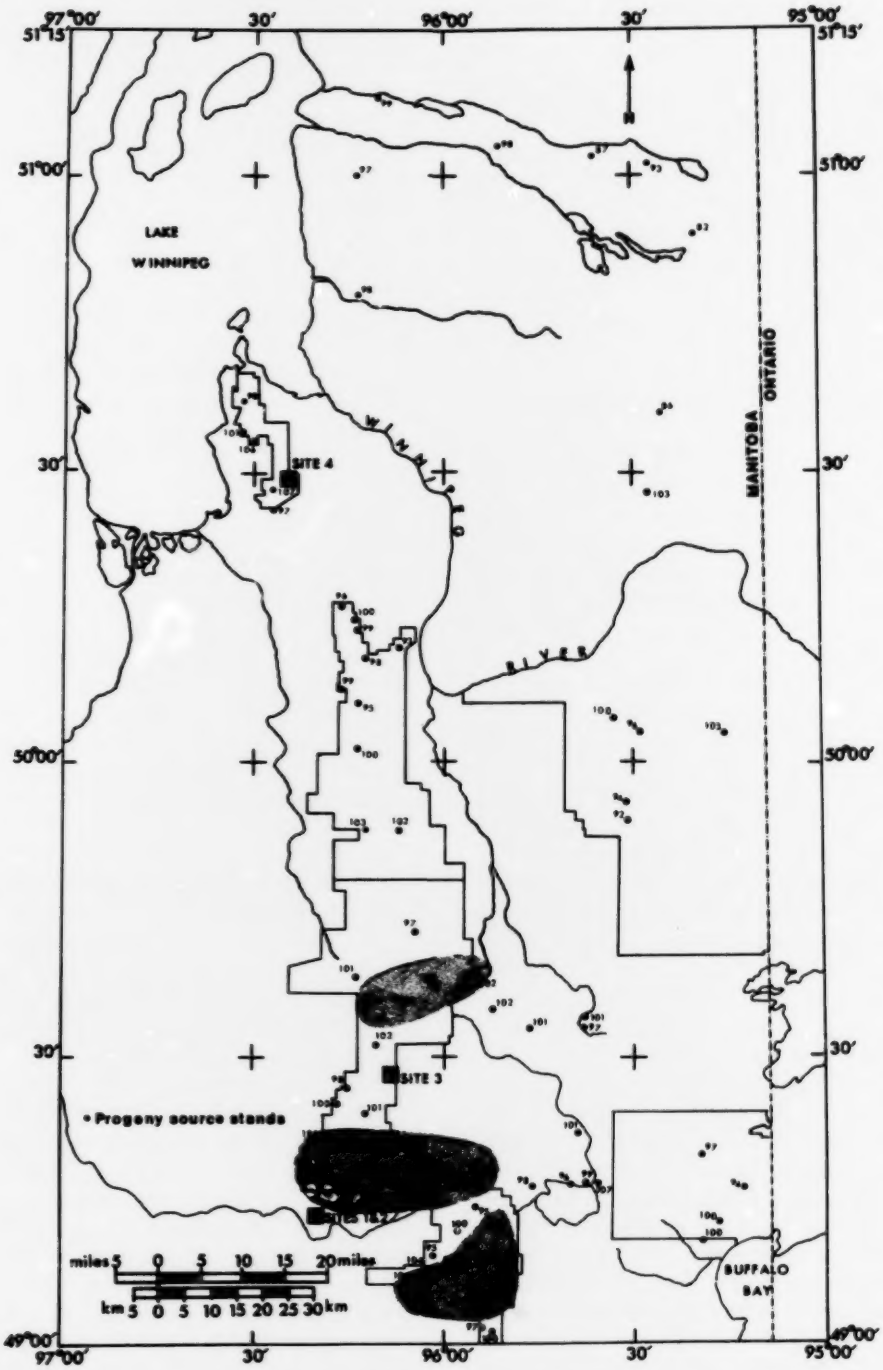

Figure 8. Five-year progeny mean heights for eastern breeding district source stands, expressed as a percentage of the test mean height (75 cm). Each percentage figure is derived from the average of the 1-5 (usually 3) progenies originating at the location of the adjacent dot. Shaded areas are recommended for seed collection.

Selection of western district parent clones for seed orchards was based on progeny mean height and on the prospects for graft production. Some of the tallest families were unavailable for selection because of lack of a parent clone, lack of scion production on parent clone grafts, or failure in previous grafting attempts.

Grafting was done at the Northern Forest Research Centre. In July 1979, 107 grafts of 18 clones having a mean progeny height of 149 cm (8% above the test mean) were delivered to Prince Albert Pulpwood Ltd. In July 1980, 154 grafts of 26 clones having a mean progeny of 148 cm (7% above the test mean) were delivered to the Saskatchewan Forestry Branch in Prince Albert. All of these grafts were planted and are being held for reselection in 1984 based on 10-year measurement results.

In 49 families with no parent clone or a weak parent clone, 5-year height of individual progeny trees was adjusted for cubic lattice block effects, and the tallest 6 trees in each family were selected as ortets of clone bank grafts.

Central Breeding District

Statistical analysis has not been done yet on the 5-year height data for the central district family test. One of the test's plantations was destroyed by fire in 1980 and data from another were unusable due to heavy browsing damage. Families were selected for seed orchard grafting based on progeny mean height in the two remaining plantations and availability of scions. The test mean height was 146 cm. In 1982, 200 scions of 28 selected parent clones were grafted at Pineland Forest Nursery. Mean progeny height of these clones was 160 cm (109% of the test mean). More than 90% of the grafts were successful.

EASTERN BREEDING DISTRICT SEEDLING SEED ORCHARD

An experimental seed-orchard plantation was planted in June 1972 with open-pollinated progenies of parent trees selected in the eastern breeding district (Klein 1974). All but one of the 209 eastern district progenies in that family test are included in the plantation along with 13 progenies not used in the family test.

The plantation is near the southwest corner of the Birds Hill Research Nursery property, at 49°59' N, 95°50' W. The soil on the planting site is a Gleyed Eutric Brunisol developed on moderately to highly calcareous medium sand lacustrine deposits. Surface horizon is neutral to slightly alkaline[8]. This site is more favorable than the eastern district family test sites for growth of jack pine because of its sufficient soil moisture. A heavy sod cover was disked and harrowed in the summer of 1971, and a fence was erected around the plantation in 1972.

The main purpose of this plantation is to produce genetically improved seed before seed production is begun in seed orchards established with genotypes selected on the basis of family-test results. The plantation can also be used for study of seed production response to management practices and of response to phenotypic selection in a genetically variable population growing in the same environment.

Plantation Design

The progenies were divided into 11 groups of 20 progenies on the basis of source proximity. Source-area boundaries

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[8] Zoltai, S.C. 1968. The soils of the Birds Hill Forest Tree Nursery site. Can. Dep. For. Rural Dev., For. Branch. Winnipeg, Manitoba. Unpublished file report.

and location of the plantation are presented in Figure 9. Accession numbers and source coordinates of the progenies in each source group are on file. Genetic improvement was sought by progressive thinning to select 1 tree out of 20 planted on each plot. Each plot originally contained one tree from each progeny in one source group. Plots were laid out as four rows of five trees at 0.6-m spacing, and adjacent plots were separated by an unplanted strip 1.2 m wide.

Every block in the plantation was planted with one tree from each of the 220 progenies, arranged in 11 source-group plots (Fig. 10). Assignment of source groups to plot positions was randomized independently for each of the plantation's 24 blocks. All seedlings planted in one block had the same within-progeny size ranking. Size rankings, recorded as block numbers, were assigned randomly to block positions. Two rows of jack pine at 1.2-m spacing surrounded the plantation.

Planting stock was reared in two randomized replicates at Birds Hill Research Nursery for three growing seasons following sowing in June 1969, except for Source Group 11, which was grown for two seasons following sowing in October 1969. Each seedling was labeled prior to planting.

The plantation's design was intended to promote effective phenotypic selection among individual trees within source groups. Close initial spacing and blocking by within-progeny size rank should have resulted in low environmental variation among trees within plots. Planting of one tree from every progeny of a source group on a plot maximized utilization of the source group's genetic variation. Trees selected by progressive thinning on source group plots were more likely to be from progenies performing best in their source group, but exceptional individuals of other progenies can be genetically superior to other trees on their plot and may have been selected in this plantation.

Progenies were stratified by source areas to reduce the influence of genotype-environment interaction on the outcome of selection. The planted progenies (which are from different parts of the eastern breeding district) may have varying relationships between their genetic merit for the entire district and their performance in the particular environment of this plantation. Trees from the same source area have similar source environments and are likely to respond similarly to the environment of the seed-orchard plantation; consequently, interaction is less likely to mask genetic differences. Outcrossing is also promoted by the grouping because the distance between source locations of adjacent selected trees in the plantation will be greater than the pollination distance in wild populations. This outcrossing is a general feature of seed orchards, except where the source range is deliberately restricted to conserve natural population attributes (Yeatman 1974), and its influence on genetic gain is not yet clear.

The plantation layout and selection thinning regime ensured a reasonably high selection intensity and regular distribution of selected trees at a moderate average spacing. Selection of 1 tree out of 20 planted provides a selection intensity marginally greater than the selection of 20 families out of 200 tested in the family test (Falconer 1960), although genetic gain will be less in the seed-orchard plantation because there is less genetic information in the performance of an individual tree than in a progeny mean. Close initial spacing allowed this selection intensity to be attained without leaving large patches of bare ground and excessive distances between trees. The risk of error arising from these forced early selection decisions was alleviated by conducting the selection thinning in stages. Following selection thinning, every selected tree occupies a 3.0 x 3.6 m area and stands at some planting position on the inner 1.8 x 2.4 m planted rectangle. The distance between selected

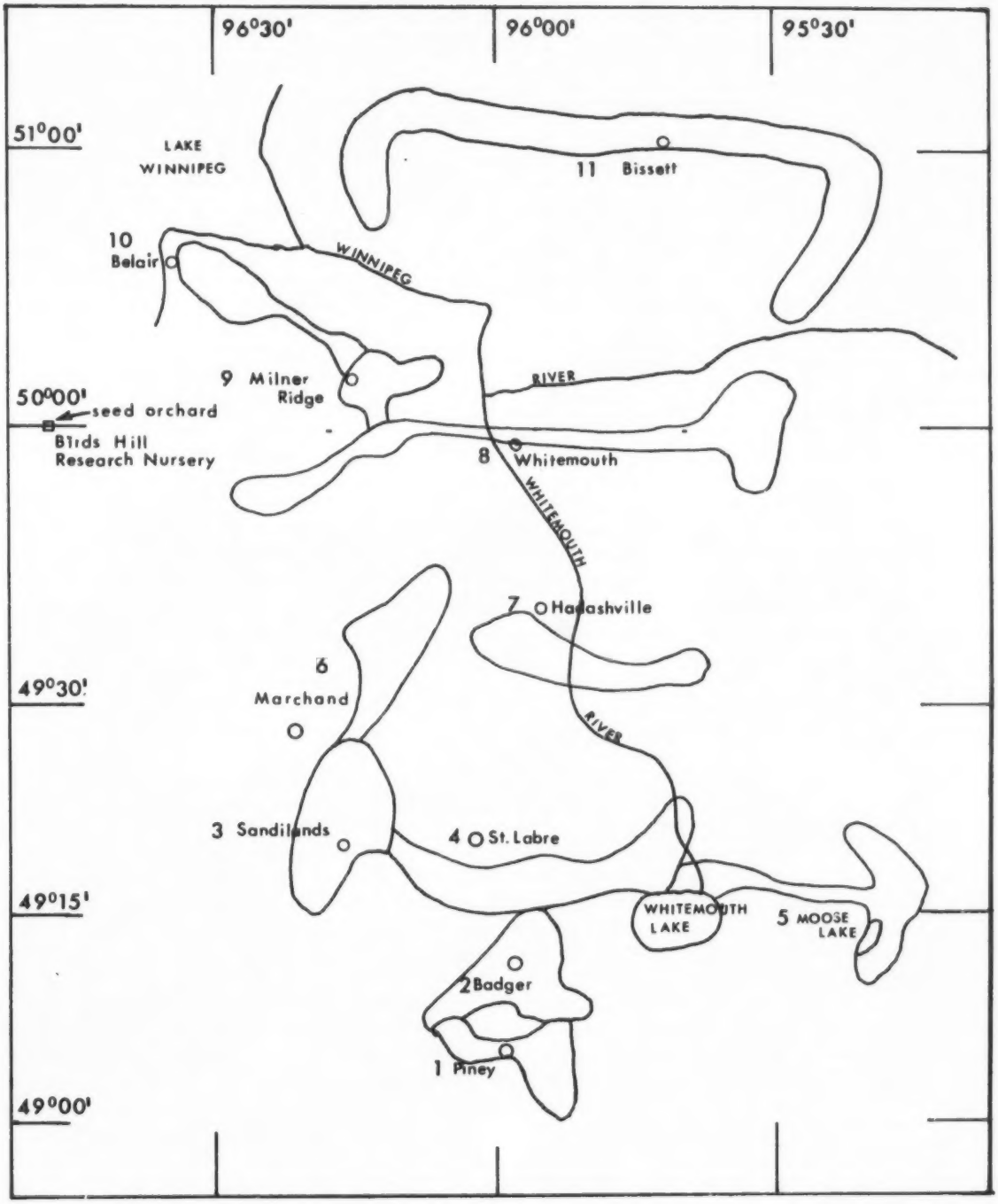

Figure 9. Source areas and plantation location for the eastern breeding district seedling seed orchard. The latitude scale is stretched south of 49°30' N and compressed north of 50°00' N to improve clarity.

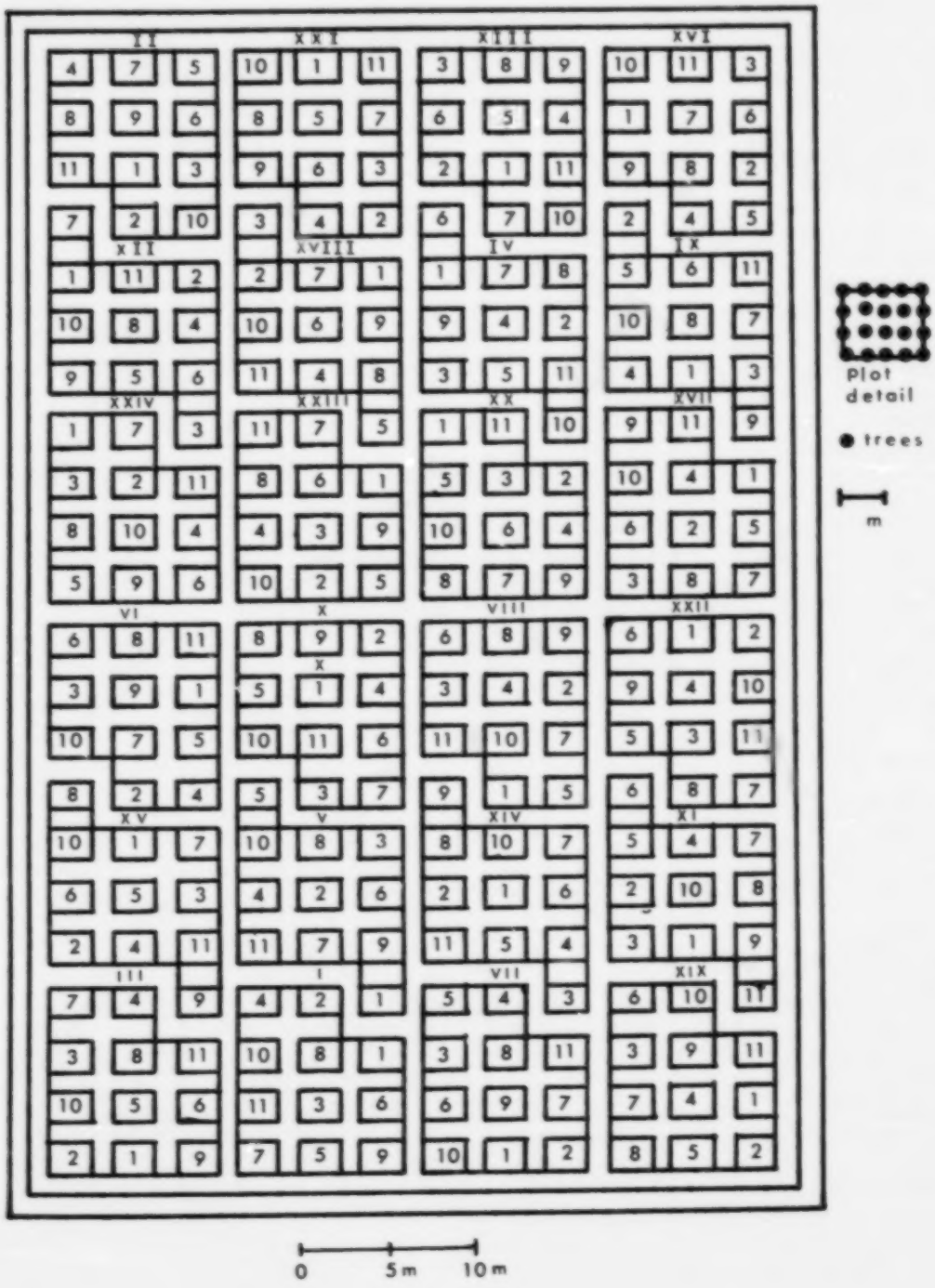

Figure 10. Plantation layout for the eastern breeding district seedling seed orchard. Roman numerals above blocks show intrafamily size rank of seedlings when planted, I >> XXIV. Numbers in plots indicate source areas.

trees on adjacent plots varies from 1.2 m to 6.3 m.

Selection Thinning

The first thinning was done following the fifth growing season after planting. First-stage selection was based primarily on height superiority, but some tall trees with stem quality defects were removed. Height of surviving trees and family number of selected trees were recorded on block layout diagrams that provided one entry space for each planting position. Blocks 1 through 10 were thinned in September 1976. The 20 planting positions on each plot were treated as 5 groups of 4 adjacent positions. If at least one tree survived in a group, then one tree was selected so that 5 well-spaced trees remained on the plot. The remaining 14 blocks were thinned in April 1977. Five trees were selected on every plot regardless of their distribution. This change in procedure was the result of a misunderstanding of instructions. Trees not selected were removed from the plantation.

Mean height was increased from 190 cm to 217 cm by the first thinning. Except for Source Group 11, source group height means ranged from 186 to 200 cm before thinning and 212 to 228 cm after thinning. Plots of Source Group 11, planted as 2-year rather than 3-year seedlings, averaged 162 and 190 cm in height before and after thinning. Block means before and after thinning ranged from 166 to 215 cm and 184 to 239 cm, respectively. Ranking of block height means was not correlated with seedling size rank before planting, according to Spearman's coefficient of rank correlation (Steel and Torrie 1960, p. 409).

The seed-orchard plantation was thinned again in 1981. The best tree on each plot was selected based on measured height and subjective judgment of stem straightness and branching habit. Trees not selected and border-row trees were removed. Most selected trees were 5-6 m in height. In November 1981 the average crop of closed cones was estimated at 10 per tree. Processing of the selection outcome and height measurement is in progress.

FUTURE PROGRAM DEVELOPMENT

Clone Bank

For about the next 5 years, a major share of the manpower and funds available to the jack pine breeding program will be allocated to filling and tending the clone bank. Grafts require tending until they have been planted and have attained sufficient size and vigor that they can be pruned of all understock shoots and no longer require either staking or hand weeding. Periodic mowing of the plantation will be continued indefinitely.

Beyond graft establishment, a management program will be initiated to enhance the clone bank's usefulness. Controlled pollination appears to offer advantages over grafting for production of seed-orchard trees. Seedlings of a full-sib progeny of two selected genotypes would be genetically variable but equal in average genetic merit to grafts of the two parent clones. The cost of each orchard tree would be lower for control-pollinated seedlings than for grafts. Furthermore, many genetically identical plants could be produced from each seedling by rooting lateral shoots induced by removal of the seedling apex. Management provisions could include controls on scion collection to maintain and enhance production, phenologically-timed shearing to stimulate scion production, and chemical applications (such as fertilizers or hormones) to stimulate strobilus production or improve scion graftability.

Family Test Measurement and Maintenance

The family tests will be measured at 5-year intervals until the plantations become too crowded to provide useful data, likely in 20-35 years. Measurement cost will increase with test age, especially when traits such as diameter, stem taper, wood density, and stem quality are measured or scored. Cost can be reduced by measuring additional traits only on progenies ranking above a specified point for mean height or another primary trait, but then application of cubic lattice analysis to adjust progeny means for block effects would be impossible for the additional traits.

Protection and maintenance of family-test plantations will be carried out as required. Competing vegetation will be controlled by use of the brush mower, brush saws, hand tools, and pulling of volunteer tree seedlings. Herbicides may be used sparingly for control of grass. Fences will be repaired, and fire guards will be tilled periodically around the perimeter of the plantations. Specific treatments for control of insect or disease outbreaks will be undertaken as required.

Selection

Clone bank grafts or exceptional test plantation trees may be selected for production of output materials following analysis of each successive measurement of a family test. Genetically superior trees will be propagated from the output materials and provided to cooperators for seed orchard establishment or expansion.

The average genetic superiority of the output materials is expected to increase over the duration of the family tests. Some potential gain from the 5-year measurement could not be utilized because some top-ranking families could not provide output materials, necessitating selection of seed parent grafts of some lower-ranked families. By the 15-year measurement, virtually all families will have clone bank grafts capable of providing either scions for successful grafting or pollen and conelets for controlled pollination. The accuracy of genetic assessment will increase as measurement age approaches timber rotation age. Scoring of additional traits will increase the correspondence between measured performance and plantation profitability. Further genetic gain will occur when measurement analysis confirms there was successful identification of superior test plantation trees.

Seed orchard trees propagated from the genotypes selected following successive measurements will be planted in additional seed orchard areas. Some genotypes will be included in several successive areas, while others will be selected at some measurements and not at others. Genotypes selected in early measurements but later falling short of selection rank should be left in the first orchard areas unless their later performance is clearly below the test average or until output of improved seed exceeds reforestation requirements.

Seedling Seed Orchard

With the completion of selection thinning to one tree per plot in the summer of 1981, fulfillment of this plantation's objectives can begin.

Seeds from the selected trees are presumed to be genetically improved. It is important that the genetic quality of this orchard's seed be determined by comparing its plantation performance with that of a control seed lot. Until that is done the plantation's design and selection thinning procedure must suffice as assurance that the plantation and its seed output merit treatment as genetically improved materials.

A plantation performance comparison of this orchard's seed with a suitable control seed lot will indicate the genetic quality of the seed. If the control lot is bulked from stored seed of the planted progenies, the performance difference will accurately represent the genetic response to selection thinning in the seed orchard plantation. Comparison with a

seed lot from eastern Manitoba stand collections will indicate total improvement from selection of the wild seed-parent trees in addition to selection thinning. The orchard seed for the test must be from cones pollinated after the second thinning. More-elaborate testing with separate seed lots for orchard blocks or source areas would add only less important information on the variability of selection response, or information that can be better obtained from family test results (Libby 1973).

Observations on cone and seed production and seed quality would be of interest whether with regard to the orchard trees in general (perhaps stratified by blocks and source areas) or about particular response to fertilizers, hormones (i.e., gibberellin), surgical treatments, or cone collection procedures. Recording of these observations during seed production stimulation trials would require additional manpower. General observations on cone production, however, are obtainable.

Initiation of the Second Selection Cycle

To initiate a second cycle of genetic improvement, full-sib families will be obtained by mating superior first-cycle genotypes, whether they are parent clones, progeny grafts, or test-plantation trees in the first-cycle population. Second-cycle improvement will be achieved primarily by selection of superior individuals within full-sib families.

The average genetic quality of each second-cycle family will be between that of each of its two parents. The genetic quality difference between the family average and the genetically best tree in a family will determine the potential gain from within-family selection. Actual genetic gain in the second selection cycle will depend upon the average size of these differences and the accuracy of genetic quality ranking within families. A description of procedures for the genetic assessment of individual trees in second generation families is beyond the scope of this report.

Genetic quality attainable in the second generation is enhanced by accurate selection of the best first-cycle genotypes. The accuracy of the genetic quality ranking of first-cycle genotypes can be improved by waiting for additional measurement periods before choosing parents or by testing control-pollinated progeny of genotypes that might merit use as parents. The second selection cycle will be delayed by a lengthy first-cycle test or if test progenies are not suitable as second-cycle families. Depending upon the marginal increment in genetic quality of selected parents and the length of the delay, the rate of genetic improvement per unit of time may not be enhanced by either measure.

Progenies produced with a pollen mixture from a large sample of first-cycle genotypes (polycross progenies) can provide ranking of their seed parents that would be highly accurate over a 15-to 30-year test. The progenies could be inexpensively produced for candidate genotypes in the clone bank and at moderate cost for family-test trees, but they would not be usable as second-cycle families because of the lack of control over inbreeding (van Buijtenen 1976). Furthermore, the marginal increment in genetic quality of selected parents would not be worth a delay of 15 to 30 years for production of second-cycle families. Polycross progeny testing is likely to be advantageous only if the delay can be reduced to about 5 years without substantial loss of the predictive value of measured performance (Libby 1973). If this approach is followed, each selected parent would be used only once (single pair mating), and there would be one second-cycle full-sib family for every pair of selected parents.

Selection among full-sib families could be used to reduce the impact of errors of ranking of the better first-cycle genotypes. More of these first-cycle genotypes than are necessary would be used as parents to produce an excess number of full-sib families. Families having the poorest average performance would then be eliminated from the

second-cycle population. Within-family selection would be conducted in the remaining families. There would be no delay in producing the second generation population, although there would be additional costs to produce, grow, and assess the excess families. In effect, the genetic quality of the parents would then be improved by progeny-testing, although the families themselves, rather than the parents, would be selected.

Inaccuracies in the ranking of first-cycle genotypes from the results of the first-cycle open-pollinated family tests would inevitably result in matings between superior and nonsuperior parents. If each parent is used in only one mating, these matings will reduce the average genetic quality of the second-cycle population whether the families are eliminated (thus losing the superior contribution) or retained (including the nonsuperior contribution). Use of each parent in several matings increases the likelihood that any superior parent will produce at least one full-sib family from a mating with another superior parent. A mating system of this sort (blocked disconnected diallel) is being used for production of a second-generation population in a Douglas-fir breeding program (Heaman 1980) and will be used for a southern US cooperative pine breeding program (Talbert 1979). This mating system would require a high expenditure on families destined to be eliminated before the true second-cycle improvement begins.

A number of important and difficult decisions will be required prior to initiation of the second cycle of improvement. Conceptual frameworks are available for use of forest genetics research results in planning multiple-generation tree-breeding strategy (Libby 1973; Namkoong 1979). Information applicable to the second cyle of this program will be provided by the open-pollinated family tests described here, and useful supporting information can be derived from reports on other programs.

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